Lasing in organic photonic-crystal structures

Doctoral Thesis

Author(s):
Harbers, Rik

Publication date:
2005

Permanent link:
https://doi.org/10.3929/ethz-a-005144013

Diss. ETH No. 16232

Lasing in Organic Photonic-Crystal Structures

A dissertation submitted to the

SWISS FEDERAL INSTITUTE OF TECHNOLOGY ZURICH

for the degree of
Doctor of Sciences

presented by

RIK HARBERS
Master of Science, University of Twente
born July 6th, 1977
Citizen of The Netherlands

accepted on the recommendation of
Prof. Dr. W. Bächtold, examiner
Dr. R.F. Mahrt, co-examiner
Prof. Dr. H. Jäckel, co-examiner

2005

Summary

In this thesis the results of a research project on optical nanostructures are presented. It is comprised of two parts: passive structures for wavelength filters that have been computationally investigated and laser structures with organic gain materials that have been designed, fabricated, and characterized. The focus of the thesis lies on the laser structures.

In the first part of the thesis wavelength filters based on high-Q resonators are designed and analyzed. An analysis method based on the temporal coupled mode theory of Haus [Haus 84] is employed. The method easily provides the transmission properties of passive resonator devices. The analysis method exploits decay rate calculations to obtain the transmission properties with a much smaller computational effort than performing full FDTD transmission calculations. The transmissions of a wavelength filter and a crossing that are obtained with the new analysis method excellently agree with the transmissions obtained using full FDTD calculations. This analysis method can thus reduce the effort required to design resonator devices where light couples into and out of the resonator. The next step would be to design 3D structures consisting of materials that are compatible with the laser structures described in the next part of the thesis.

In the second part of the thesis two different types of laser structures are designed, fabricated, and characterized. First, an organic photonic crystal laser is investigated whose mode coupling is enhanced by using a thin layer of high-index titanium dioxide (TiO_2). In the titanium dioxide layer a photonic crystal is etched. The gain material is the polymer methyl-substituted ladder-type poly(*para*-phenylene) (MeLPPP). Calculations of the out-of-plane coupling constant show that the titanium-dioxide photonic-crystal layer increases the coupling constant by a factor of twenty compared to the out-of-plane coupling constant of a laser structure where the photonic crystal is etched into glass. Combining the out-of-plane coupling constant with the in-plane coupling constant the gain thresholds of the organic photonic crystal lasers can be calculated. The minimization of the gain threshold gives the optimum titanium-dioxide layer thickness. The smaller the device is, the thicker the titanium-dioxide layer has to be. The titanium-dioxide layer allows for lower thresholds and smaller devices.

With this knowledge 1D and 2D lasers have been designed and fabricated. For 1D grating lasers the increase of the mode coupling results in a low laser threshold that is twice as low as lasers where the grating is etched into glass. For 2D photonic crystal lasers this decrease is a factor of five. The computationally predicted and experimentally measured spectral features show excellent agreement. Furthermore, the lasers with a thin layer of TiO_2 can be significantly smaller while retaining the same low threshold. The smallest device featuring lasing measured 25 μm$\times$25 μm. The measured threshold behavior qualitatively matches the predictions from the simulations.

The second type of lasers are interferometrically structured lasers. They are fabricated by using the interferometric pattern of multiple laser beams to expose a photo-resist in which the gain material is incorporated. These structures exhibit lasing and the spectral behavior of the laser agrees very well with the predictions from computations. The lasing threshold is more than three orders of magnitude higher than the lowest thresholds of the lasers with titanium-dioxide layer. However, these structures can be fabricated much easier than other structures. Furthermore, many improvements are still possible, which merits further research of interferometrically structured lasers.